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RESONANT TRANSDUCERS IN LIQUID-FILLED CYLINDERS,(U)
1962 C C SIMS, T A HENRIQUEZ

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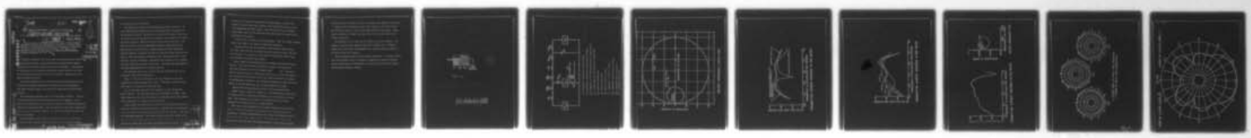

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RESONANT TRANSDUCERS IN LIQUID-FILLED CYLINDERS

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Cavity-loaded piston transducers can be made to work at high hydrostatic pressure by operating the resonator in a liquid-filled cylinder. The measured and theoretical performance of transducers of this type with various fluids is given. This paper is an extension of the work reported in the Journal of the Acoustical Society of America, September 1962.

To design transducers that can be used at very great depths without any deleterious effects on their performance characteristics requires techniques that entirely avoid pressure release materials. Some progress is being made in the fabrication of pressure release material, but thus far the stability desired has not yet been achieved, especially at very high hydrostatic pressure.

An alternate approach is the use of fluid-filled transducers and the control of the acoustic parameters to achieve the desired properties. This paper describes some of the results of experiments directed toward this end.

The transducers generally were of the type shown on Slide 1. This is the design reported on in the September issue of the Journal. It is a double mass-loaded ceramic stack with the weight of the vibrating structure supported on the back O-rings. The slit around the front mass is kept very small so that the acoustic impedance is high and essentially isolates the back of the piston.

The cylindrical sleeve around the dumbbell is of $\frac{1}{2}$-inch-thick steel. The depth of the cavity in front of the piston can be varied to change

 254 300

the acoustic load on the piston.

The equivalent circuit can be represented as shown in Slide 2. We have represented the impedance due to the liquid between the masses as the cotangent function. The presence of the oil or O-ring in the slit is the primary cause of dissipation, and requires some juggling of the shunt acoustical impedance against the series viscous loss in the slit. The motion around this area is undoubtedly much more complicated than we would be able to describe with a simple lumped electrical equivalent circuit; however, the general concepts are much more easily seen with the analog. Also, the coupling of vibration from the walls and back to the water has not been considered. Apparently this radiation is not significant below the first resonance of the case. The cavity is represented by the Mason approximation for a transmission line.

The following slides will show the measured characteristics of the resonators under various conditions.

Slide 3 - This is a VILP pattern with the resonator in the tube supported on the back O-rings with no oil. This gives an idea of the Q when there is no restraint on the front mass.

The smaller curve represents the transducer in air, filled with mineral spirits. The very small loop is the transducer in water. The detail cannot be seen but the contrast is interesting because the difference in magnitude is a measure of the efficiency.

Slide 4 gives the characteristics of the first transducer without oil (that is, air-backed, with an O-ring seal), compared with the characteristics when castor oil completely fills the cavity and cylinder. Two things are immediately apparent. The loss is higher and there is a hole in the response at the frequency corresponding to approximately half a wavelength between the masses when the cavity and cylinder are oil filled. To assure ourselves that there was no mistake in interpretation, we padded the inside of the back mass with corprene, which shifted the phase, and the hole disappeared from this region. These results are for the optimum cavity depth, that is, the depth that tunes the cavity to couple in with the mechanical resonance.

Slide 5 shows the effect of cavity detuning. Here, the cavity resonance shifts from below to the region of mechanical resonance.

The major effort has been directed toward finding a better fluid. The ideal fluid will have the sound speed and density of water, and very low viscosity. As a matter of fact, water is the perfect fluid if you want to bother to insulate the ceramic.

Slide 6 shows the characteristics of a resonator filled with mineral spirits. The inside chamber was reduced in length, thus moving the half-wave resonance out of the frequency range of interest. The sound speed in mineral spirits is lower than that in water so that the depth of the cavity had to be reduced to shift the cavity resonance up to couple to the mechanical resonance. The viscosity of kerosene is about 2.0 centipoise, so that the efficiency here is high, between 80 and 90%.

Typical directivity patterns are shown in the following slides.

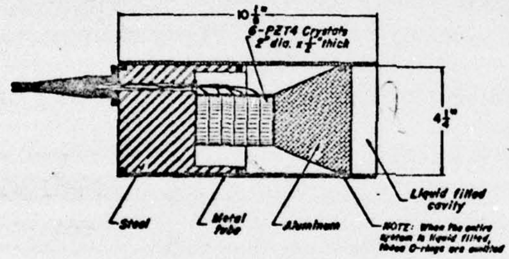
Slide 7 shows a castor oil filled unit. The directivity in each case is compared with the theoretical directivity of a flat piston in a long tube. The influence of the cavity on the directivity has not been explained, but obviously there is a marked effect.

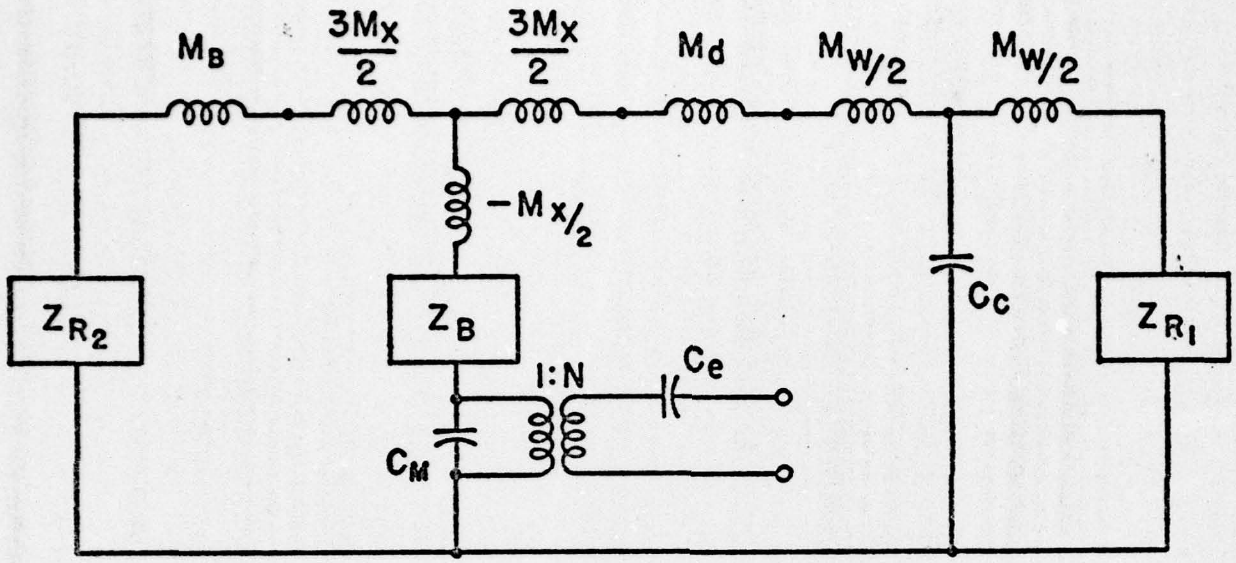
There are several possibilities for adding flexibility to this technique. A cavity can be added to the back mass to further control the directivity. Certain cavity dimensions will reduce the radiation load to less than the value for a plane piston. This would serve to reduce the power out to less than that from the plane piston. High density tungsten can be used also to reduce the area of radiation while keeping a high mass.

Slide 8 shows a transducer with mineral spirits in the front cavity 3/4 inch deep, water in a back cavity approximately $1\frac{1}{2}$ inch deep. Notice the back radiation is about 9 dB lower than it is when the case has no cavity in the back.

The impedance in the fluid can be tailored to aid the response. For example, a quarter-wave condition makes this cotangent zero. Between a quarter and a half wave, this impedance is a positive reactance which can be used to lower the resonance.

The work reported here has been largely exploratory. It seems, however, that this technique could be valuable in deep-water transducer problems, and in arrays where the flexibility of acoustic load could aid in improving the mutual impedance loading.


6-PZT4 Crystals
Steel
Metal tube
Aluminum
Liquid filled cavity
NOTE: When the entire system is liquid filled, these O-rings are omitted



C_e = electrical capacitance of free ceramic

C_M = mechanical compliance of open-circuit ceramic

Z_B = impedance of fluid between masses $\approx -j\rho c A_B / \tan kl$

$M_x = 0.4 M_T$, where M_T = total mass of ceramic stack

M_d = mass of aluminum horn

M_B = mass of back plate

M_w = mass of fluid in cavity

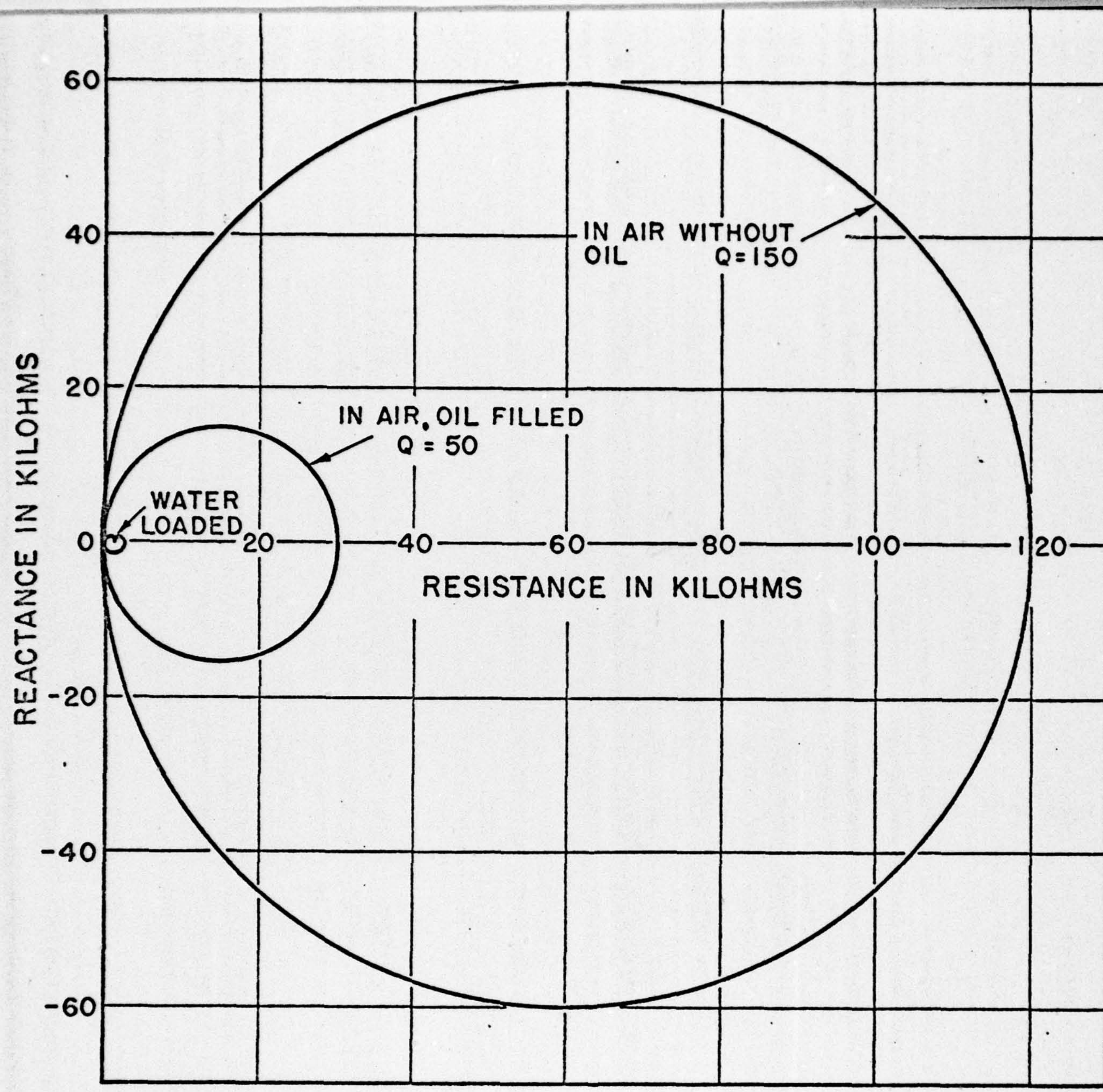
C_c = compliance of fluid in cavity

Z_{R1} = radiation load at front of cavity

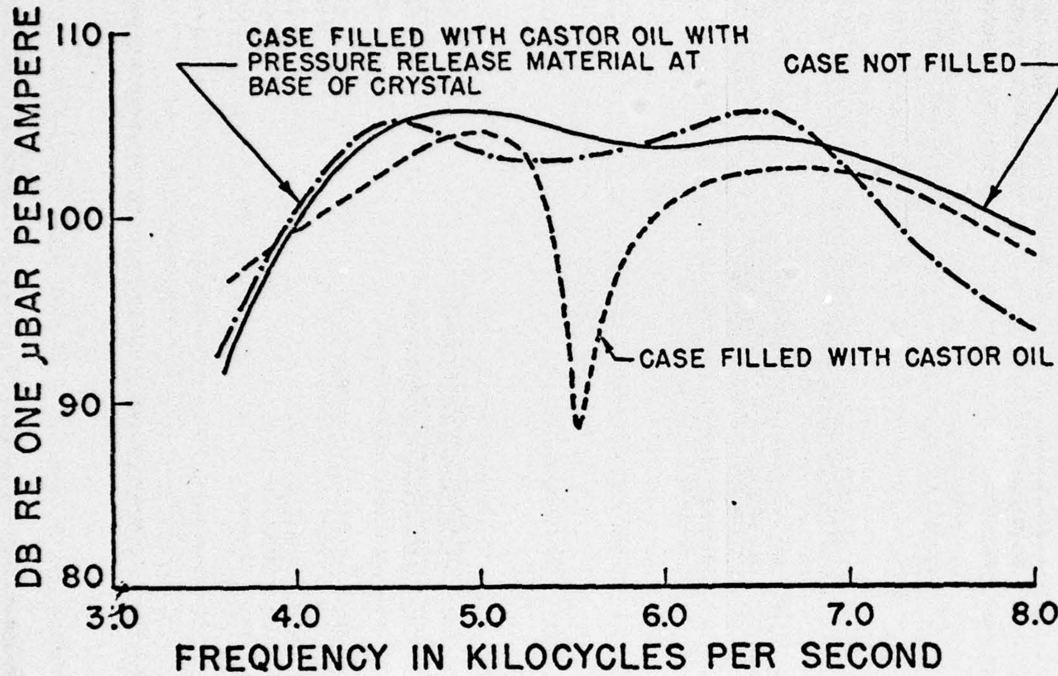
Z_{R2} = radiation load at back mass

N = transducer turns ratio

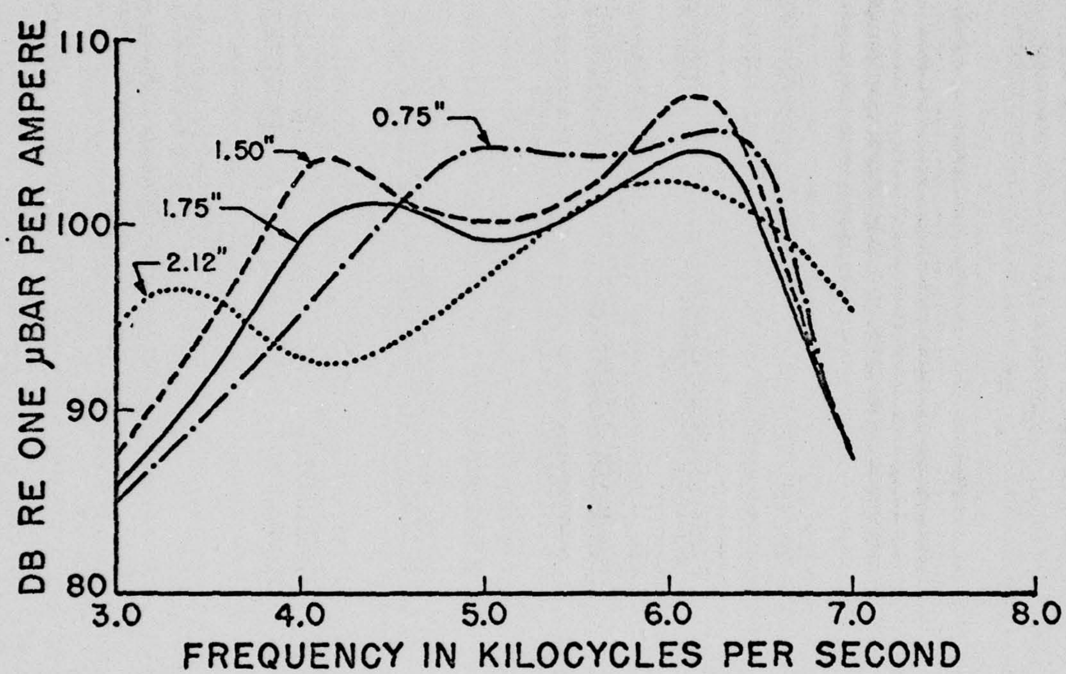
Slide 2



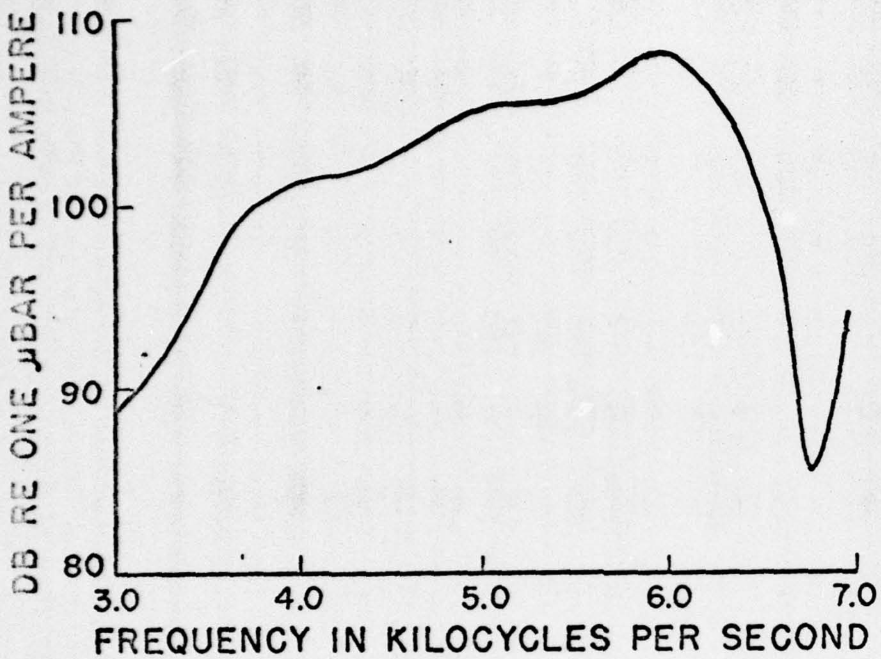
VECTOR IMPEDANCE LOCUS PLOT



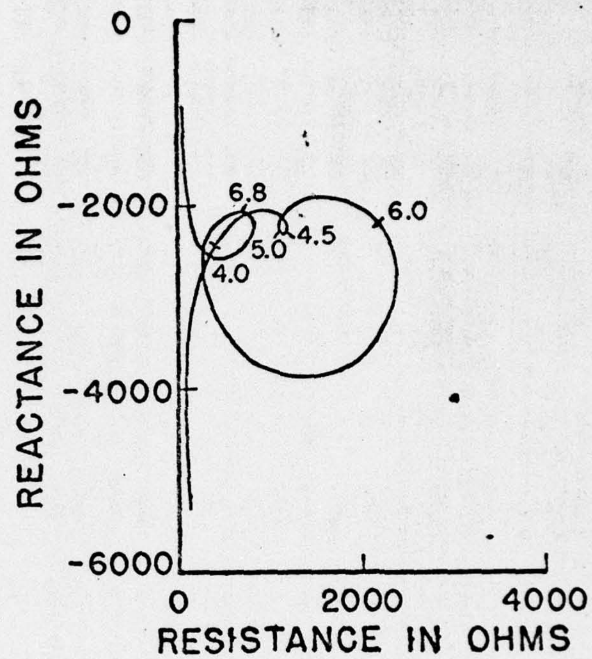
TRANSMITTING CURRENT RESPONSE AT ONE METER



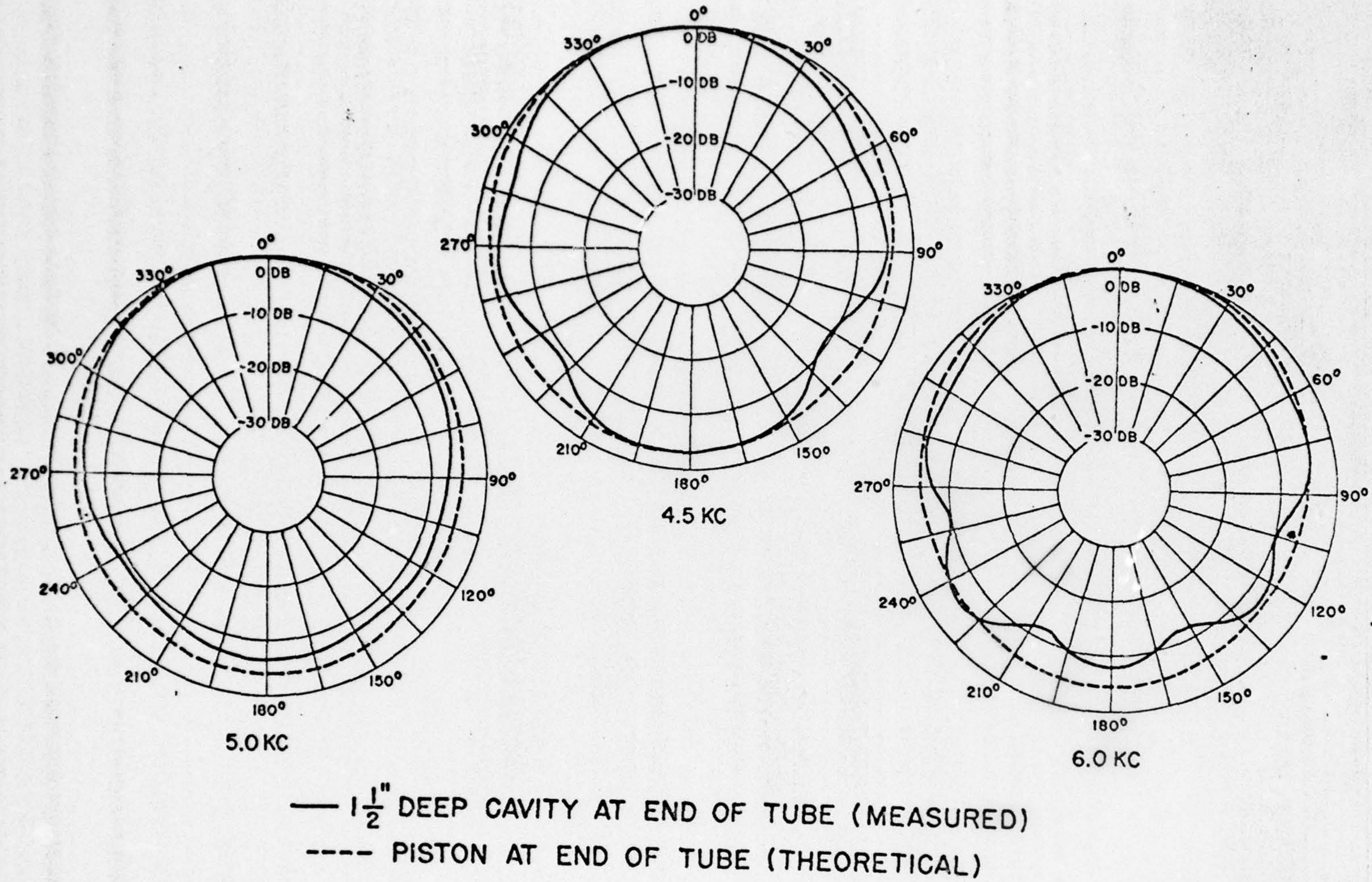
TRANSMITTING CURRENT RESPONSE AT ONE METER



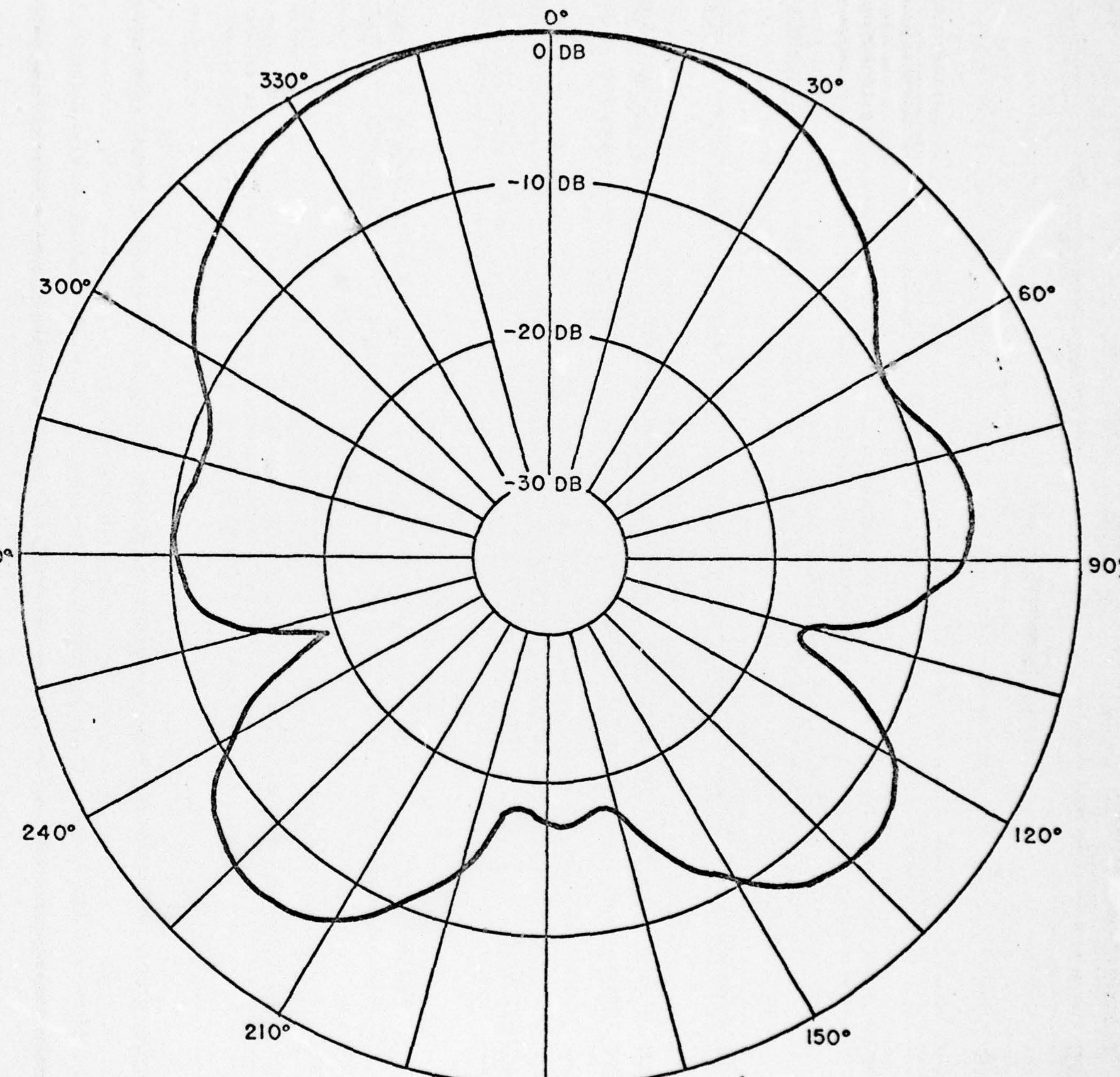
TRANSMITTING CURRENT RESPONSE AT ONE METER



VECTOR IMPEDANCE PLOT


0°
30°
60°
90°
120°
150°
180°
210°
240°
270°
300°
330°
0 DB
-10 DB
-20 DB
-30 DB
5.0 KC
4.5 KC
6.0 KC
— $1\frac{1}{2}$" DEEP CAVITY AT END OF TUBE (MEASURED)
---- PISTON AT END OF TUBE (THEORETICAL)

~~Fig. 7.~~
Slide 7



$\frac{3}{4}$" DEEP CAVITY IN FRONT

6.0 KC

$1\frac{1}{2}$" DEEP CAVITY IN BACK